Unit 4
Cell Division

Chapter 9: The Cell Cycle and Mitosis

Cell Division

- All the DNA in a cell constitutes the cell's **genome**
- DNA molecules in a cell are packaged into **chromosomes**
- Eukaryotic chromosomes consist of **chromatin**, a complex of DNA and protein

- **Somatic cells** = body or nonreproductive cells
  - Diploid
    - Have two sets of chromosomes
  - Produced by mitosis
  - Humans: 46 total chromosomes
    - 2 sets of 23 (one set from each parent)

- **Gametes** = reproductive cells: sperm and eggs
  - Haploid
    - Have one set of chromosomes
  - Produced by meiosis
  - Humans: 23 chromosomes

- Before cell division, DNA is copied so each daughter cell ends up with a complete genome
- Each duplicated chromosome has two **sister chromatids**
  - Joined identical copies of the original chromosome
  - The **centromere** is where the two chromatids are most closely attached
- During cell division, the two sister chromatids of each duplicated chromosome separate and move into two nuclei
  - Once separate, the chromatids are called chromosomes
- Thus each new nucleus receives chromosomes identical to that of the parent cell

- Eukaryotic cell division consists of
  - **Mitosis**
    - Division of the genetic material in the nucleus
  - **Cytokinesis**
    - Division of the cytoplasm
- Gametes are produced by a variation of cell division called **meiosis**
  - Meiosis yields nonidentical, haploid daughter cells
- **Fertilization** restores diploid number

The Cell Cycle

- The cell cycle consists of
  - **Interphase** (about 90% of the cell cycle)
    - G_1 phase (cell growth)
    - **S phase** (synthesis of DNA)
      - Chromosomes are copied
    - G_2 phase (cell growth)
  - **Mitosis** (division of nuclear material)
    1. Prophase
    2. Prometaphase
    3. Metaphase
    4. Anaphase
    5. Telophase
  - **Cytokinesis** (division of cytoplasm)

Figure 9.7c

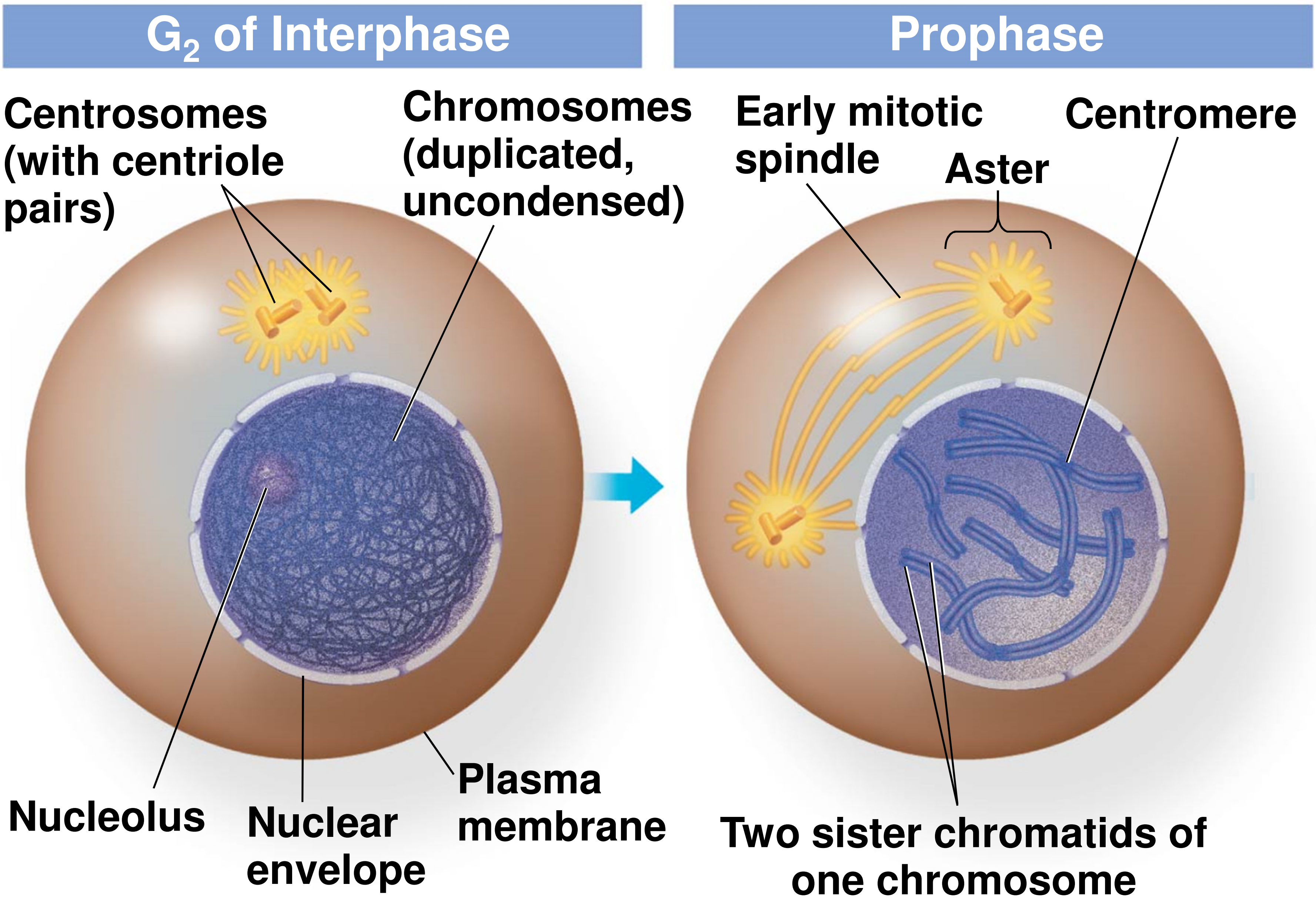

G_2 of Interphase
Prophase
Centrosomes (with centriole pairs)
Chromosomes (duplicated, uncondensed)
Early mitotic spindle
Aster
Centromere
Nucleolus
Nuclear envelope
Plasma membrane
Two sister chromatids of one chromosome

Figure 9.7d

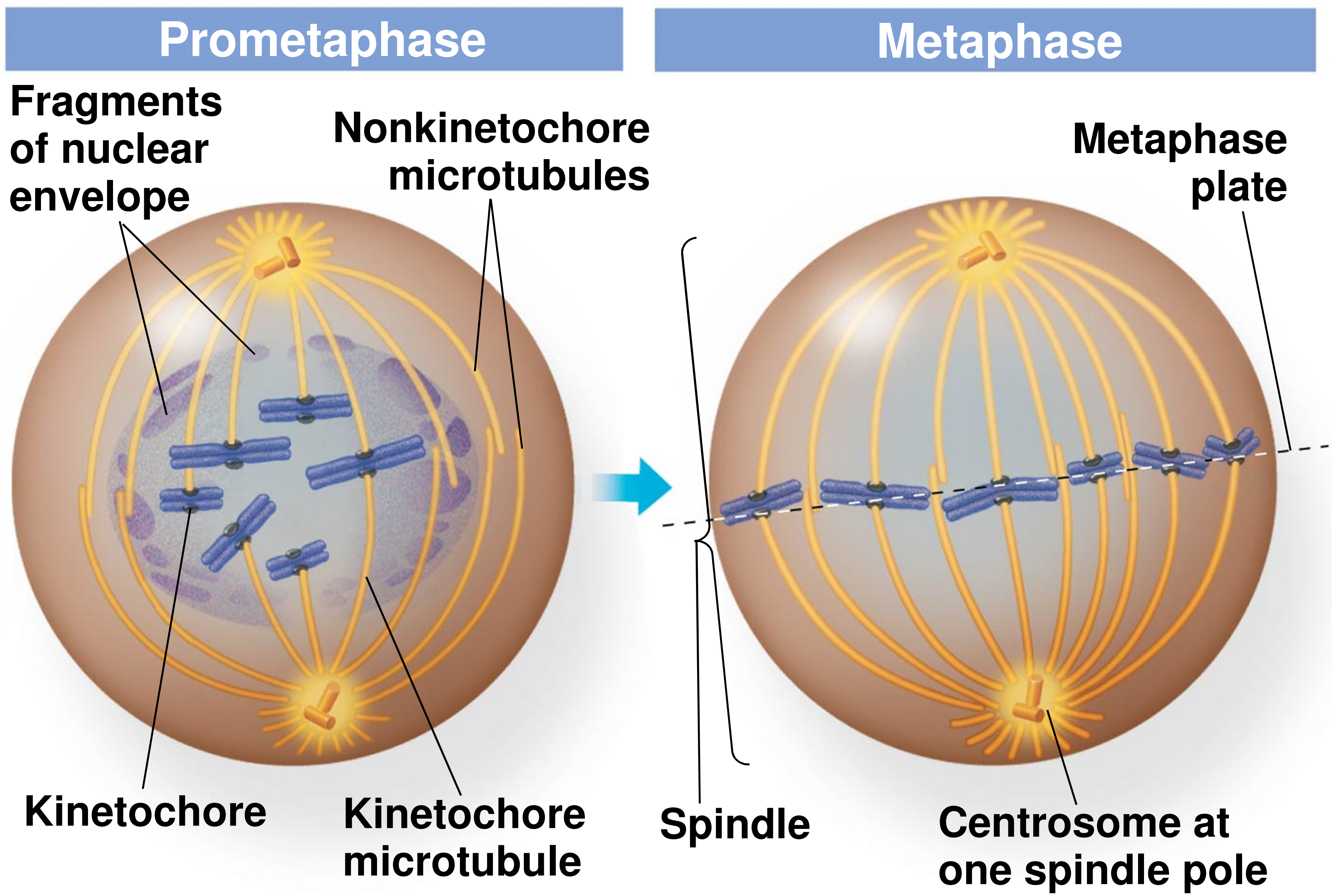
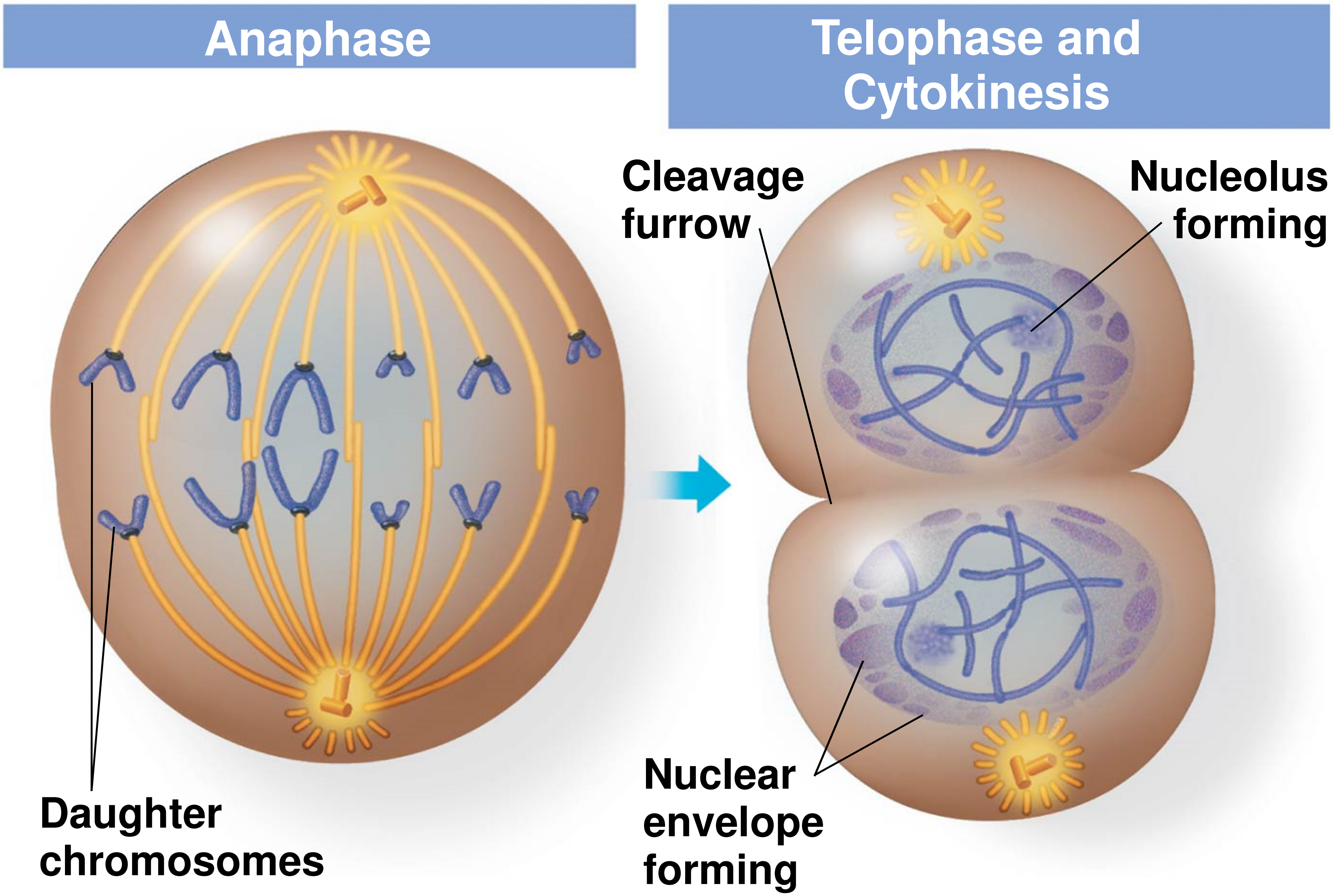

Prometaphase
Metaphase
Fragments of nuclear envelope
Nonkinetochore microtubules
Metaphase plate
Kinetochore
Kinetochore microtubule
Spindle
Centrosome at one spindle pole

Figure 9.7e



Anaphase
Telophase and Cytokinesis
Cleavage furrow
Nucleolus forming
Daughter chromosomes
Nuclear envelope forming

Mitosis

PROPHASE

- Chromatin condenses into discrete chromosomes
  - Appear as 2 identical sister chromatids joined at centromere
- Mitotic spindle begins to form
- Centrosomes separate

PROMETAPHASE

- Nuclear envelope fragments
- Some spindle microtubules attach to the chromosomes and begin to move them

METAPHASE

- Chromosomes line up at the **metaphase plate**
  - Imaginary structure at the midway point between the spindle's two poles

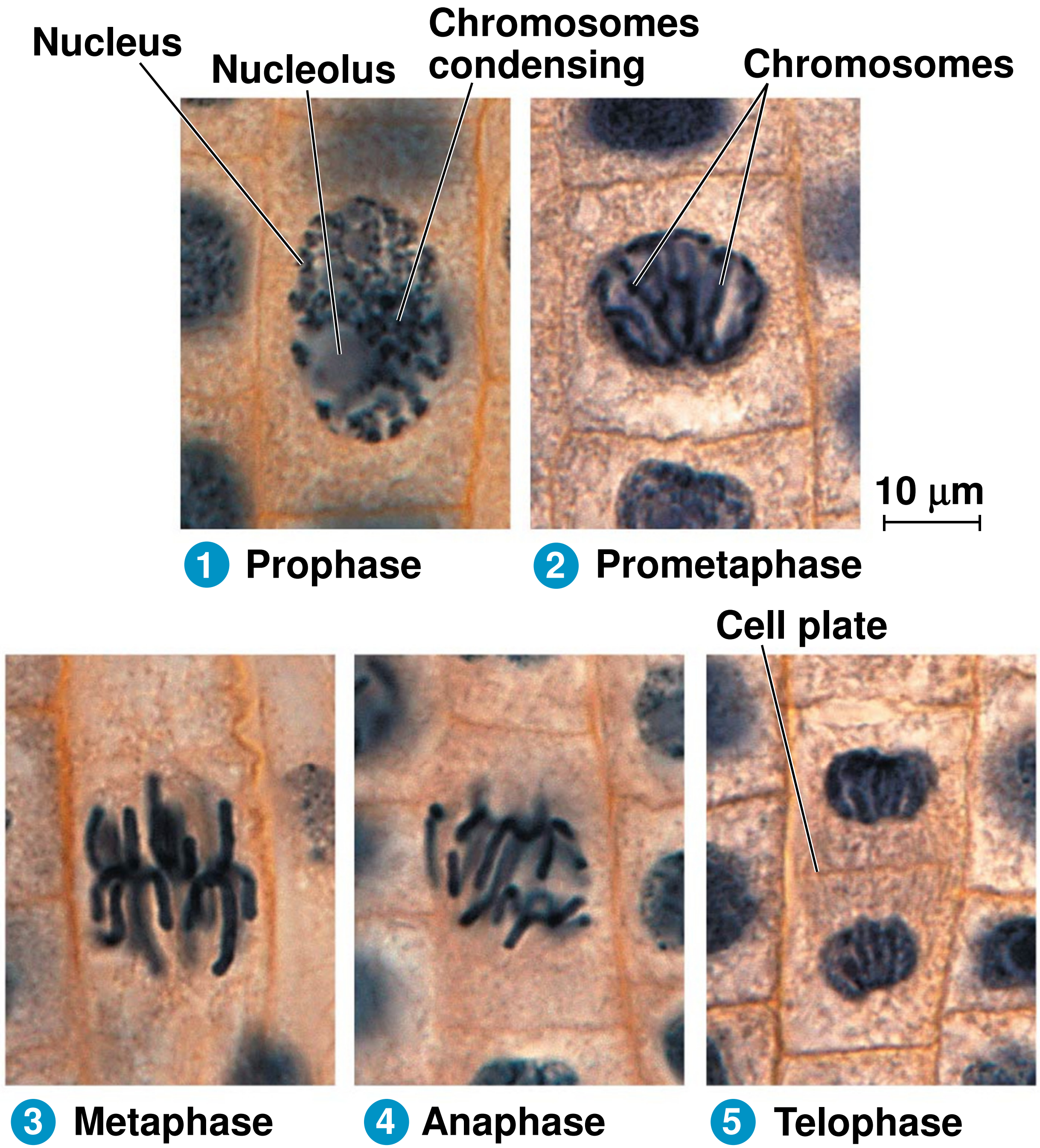
ANAPHASE

- Sister chromatids separate and move toward opposite ends of the cell

TELOPHASE

- 2 daughter nuclei form in the cell
  - Nuclear envelopes reform

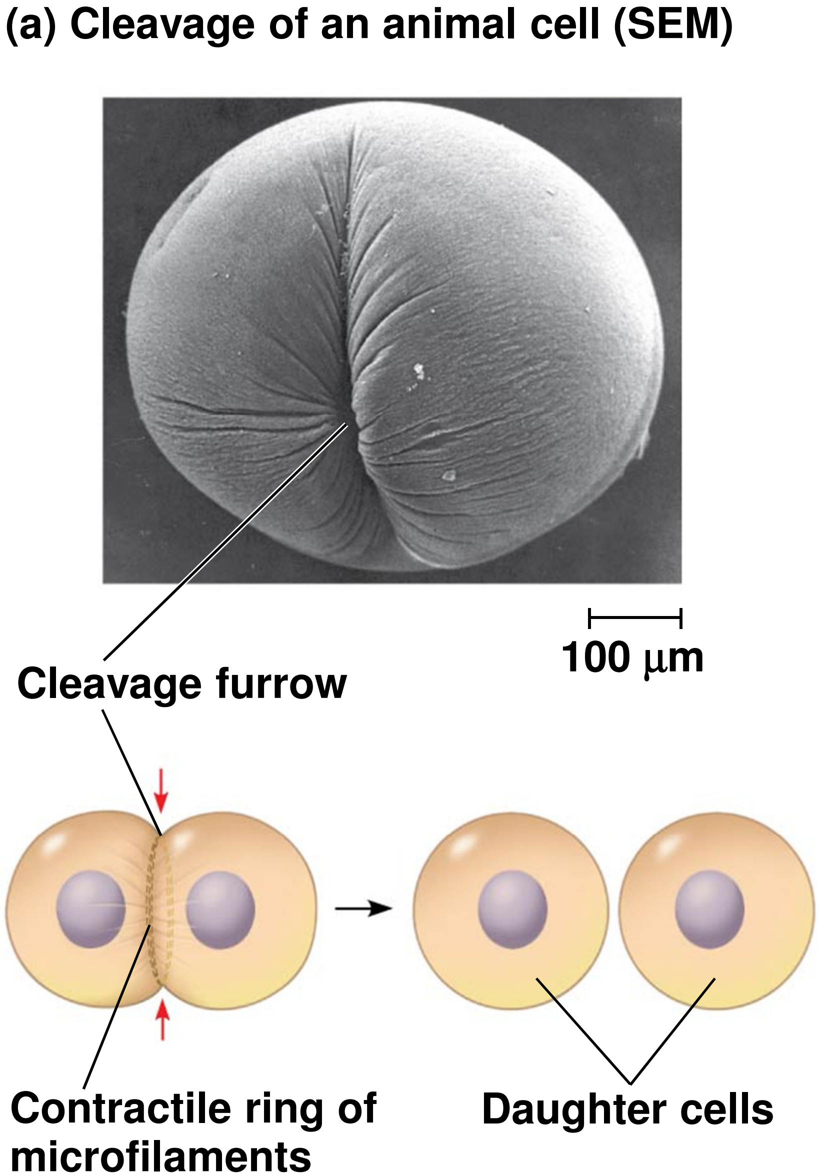
Figure 9.11


Nucleus
Nucleolus
Chromosomes condensing
Chromosomes
10 µm
1 Prophase
2 Prometaphase
Cell plate
3 Metaphase
4 Anaphase
5 Telophase

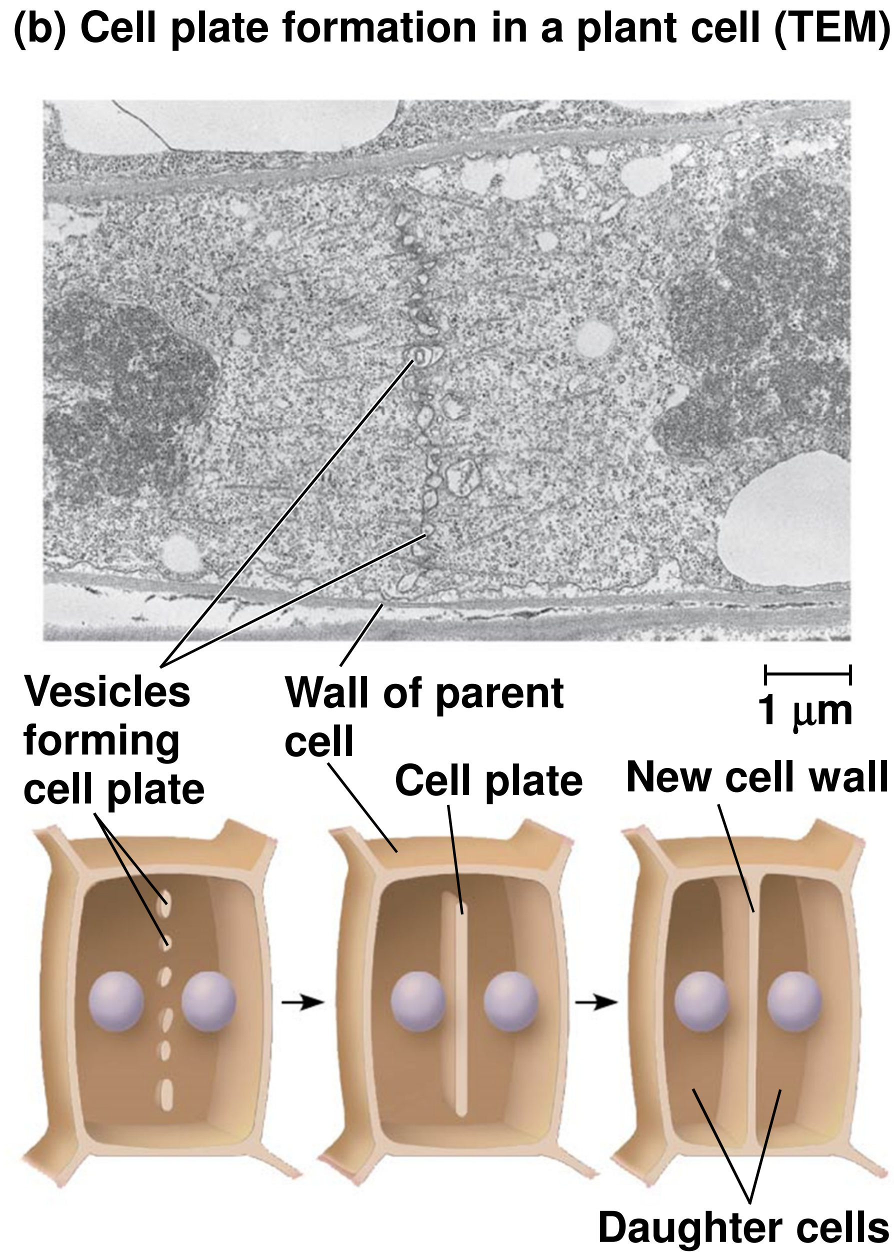
Cytokinesis

- Division of cytoplasm
- In animal cells, cytokinesis occurs by a process known as **cleavage**, forming a **cleavage furrow**
  - Shallow groove in cell surface near old metaphase plate
- In plant cells, a **cell plate** forms during cytokinesis
  - Becomes cell wall

Figure 9.10



(a) Cleavage of an animal cell (SEM)
100 µm
Cleavage furrow
Contractile ring of microfilaments
Daughter cells

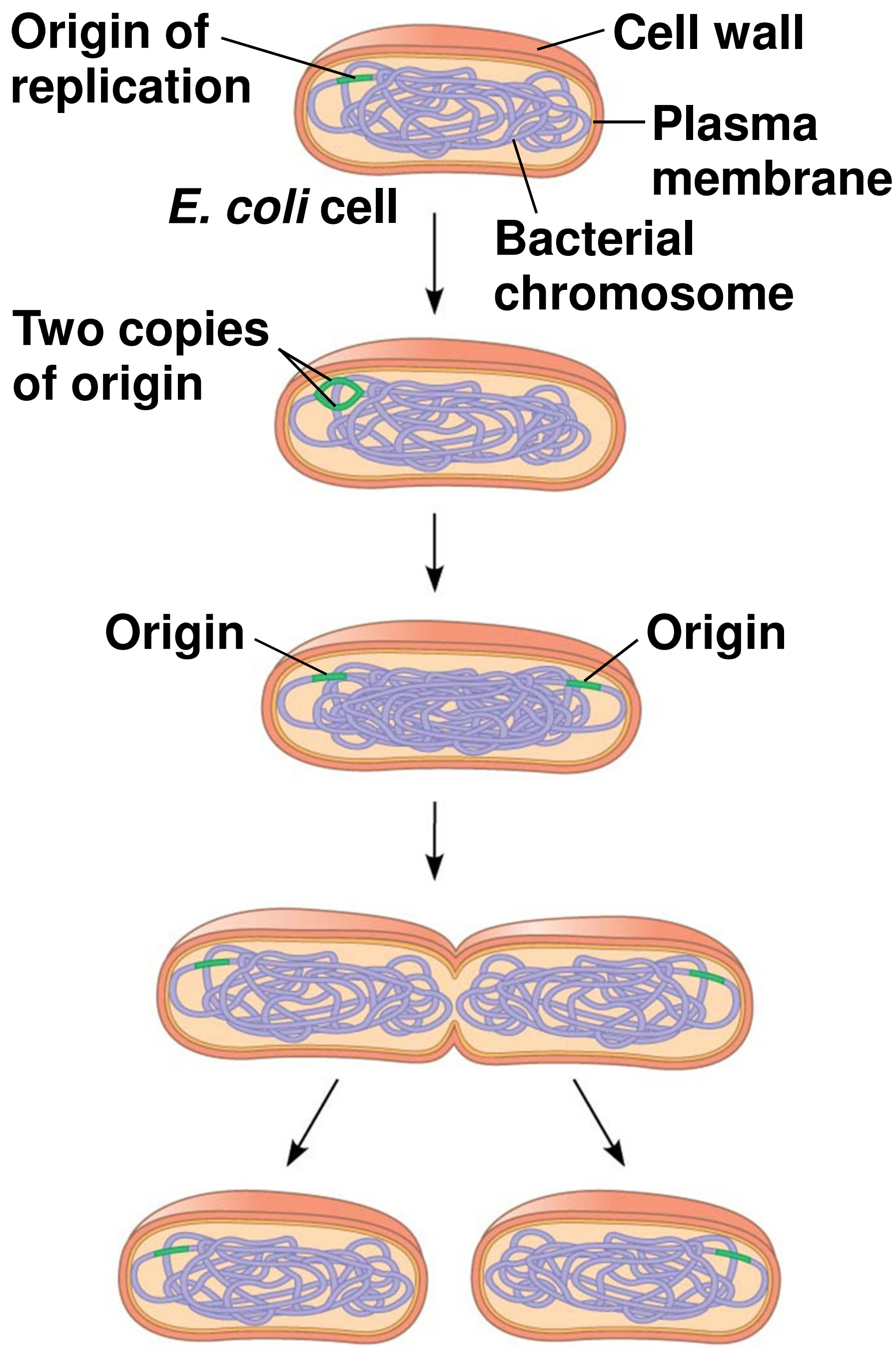


(b) Cell plate formation in a plant cell (TEM)
Vesicles forming cell plate
Wall of parent cell
1 µm
Cell plate
New cell wall
Daughter cells

Binary Fission in Bacteria

- Prokaryotes reproduce by a type of cell division called **binary fission**
  - Asexual reproduction where cell grows and divides into 2 cells
  - Does NOT involve mitosis in prokaryotes
- The single chromosome replicates
- The plasma membrane pinches inward, dividing the cell into two

Figure 9.12-4

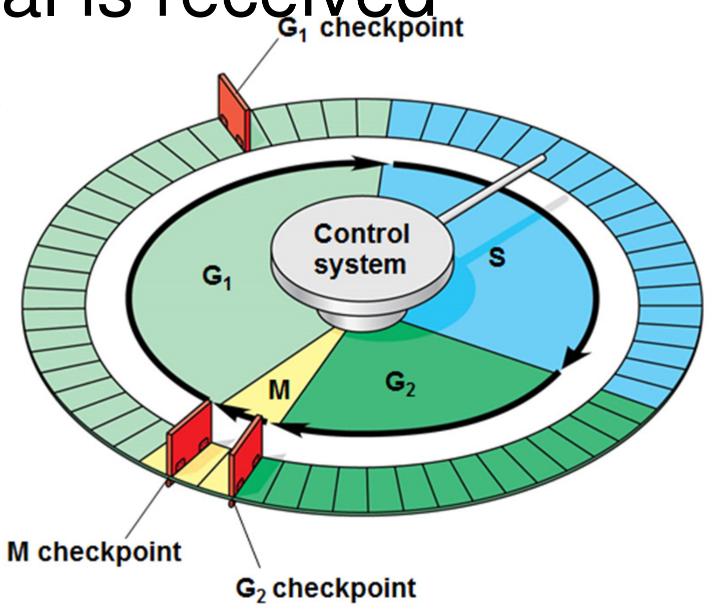


1. Chromosome replication begins.
2. One copy of the origin is now at each end of the cell.
3. Replication finishes.
4. Two daughter cells result.

Regulation of Cell Cycle

- The frequency of cell division varies with the type of cell
  - Human skin cells divide frequently
  - Fully formed nerve and muscle cells do not divide at all when mature
- These differences result from regulation at the molecular level
- Cancer cells manage to escape the usual controls on the cell cycle

- **Cell cycle control system**
  - Directs the sequential events of the cell cycle
    - Similar to a timing device of a washing machine
  - Regulated by both internal and external controls
- The clock has specific **checkpoints** where the cell cycle stops until a go-ahead signal is received
  - If the cell does not receive the go-ahead signal, it will exit the cycle, switching into a nondividing state called the **G_0 phase**



- The cell cycle is regulated by a set of regulatory proteins and protein complexes including
  - **Kinases**
  - **Cyclins**
- Some external signals are
  - **Growth factors**
    - Proteins released by certain cells that stimulate other cells to divide
  - **Density-dependent inhibition**
    - Crowded cells stop dividing
  - **Anchorage dependence**
    - Cells must be attached to a substratum to divide

Cancer Cells

- Cancer cells do not respond to signals that normally regulate the cell cycle
- Cancer cells may not need growth factors to grow and divide
- Cancer cells exhibit neither density-dependent inhibition nor anchorage dependence

Unit 4
Cell Division

Chapter 10: Meiosis

Vocab

- **Heredity** is the transmission of traits from one generation to the next
- **Variation** is demonstrated by the differences in appearance that offspring show from parents/siblings
- **Genetics** is the scientific study of heredity and variation
- **Genes** are the units of heredity and are made up of segments of DNA
- Genes are passed to the next generation via reproductive cells called **gametes** (sperm and eggs)
- DNA is packaged into **chromosomes**
- Each gene has a specific location, or **locus**, on a certain chromosome

Asexual VS Sexual Reproduction

- In **asexual reproduction**, a single individual passes genes to its offspring without the fusion of gametes
  - Make exact genetic copies of themselves
- A **clone** is a group of genetically identical individuals from the same parent
- In **sexual reproduction**, two parents give rise to offspring that have unique combinations of genes inherited from the two parents
  - Genetic variation is an important consequence of sexual reproduction

Sets of Chromosomes in Human Cells

- Human somatic cells have 23 pairs of chromosomes
- A **karyotype** is an ordered display of the pairs of chromosomes from a cell
- The two chromosomes in each pair are called **homologous chromosomes**, or homologs
  - Same genes
  - Same order (loci)
  - Different alleles
- The **sex chromosomes** determine the gender
  - Human females = XX
  - Human males = XY
- The remaining 22 pairs of chromosomes = **autosomes**

- A **diploid cell** ($2n$) has two sets of chromosomes
  - For humans, the diploid number is 46 ($2n = 46$)
- Each pair of homologous chromosomes includes one chromosome from each parent
- In a cell in which DNA synthesis has occurred, each chromosome is replicated
  - Each replicated chromosome consists of two identical sister chromatids

- Gametes (sperm or egg) contains a single set of chromosomes and is **haploid** (n)
  - For humans, the haploid number is 23 ($n = 23$)
- Each set of 23 consists of 22 autosomes and a 1 sex chromosome

- **Fertilization** is the union of gametes (the sperm and the egg)
- The fertilized egg is called a **zygote**
  - Diploid
  - Has one set of chromosomes from each parent
- The zygote produces somatic cells by **mitosis** and develops into an adult

- At sexual maturity, the ovaries and testes produce haploid gametes
  - **Gametes** are the only types of human cells produced by **meiosis** rather than mitosis
- Meiosis reduces the number of sets of chromosomes, resulting in one set of chromosomes in each gamete
  - Otherwise, the number of chromosomes would double each time during fertilization
- Fertilization and meiosis alternate in sexual life cycles to maintain chromosome number
  - Contributes to genetic diversity

Meiosis

- Like mitosis, meiosis is preceded by the replication of chromosomes
- Unlike mitosis
  - Two sets of cell divisions
  - Results in
    - 4 daughter cells
    - Nonidentical
    - Haploid
      - Half as many chromosomes as parent

- Remember,
  - Sister chromatids are IDENTICAL copies of the same chromosome
  - Homologs are individual chromosomes that were inherited from different parents
    - They have the same genes at the same loci, but are NOT identical copies
    - They may have different versions of those genes, each called an *allele*

- Meiosis cuts chromosome number in half
  - Meiosis I
    - Homologous pairs of chromosomes pair and separate
  - Meiosis II
    - Sister chromatids of each chromosome separate
- Four new haploid cells are produced as a result

Figure 10.7a

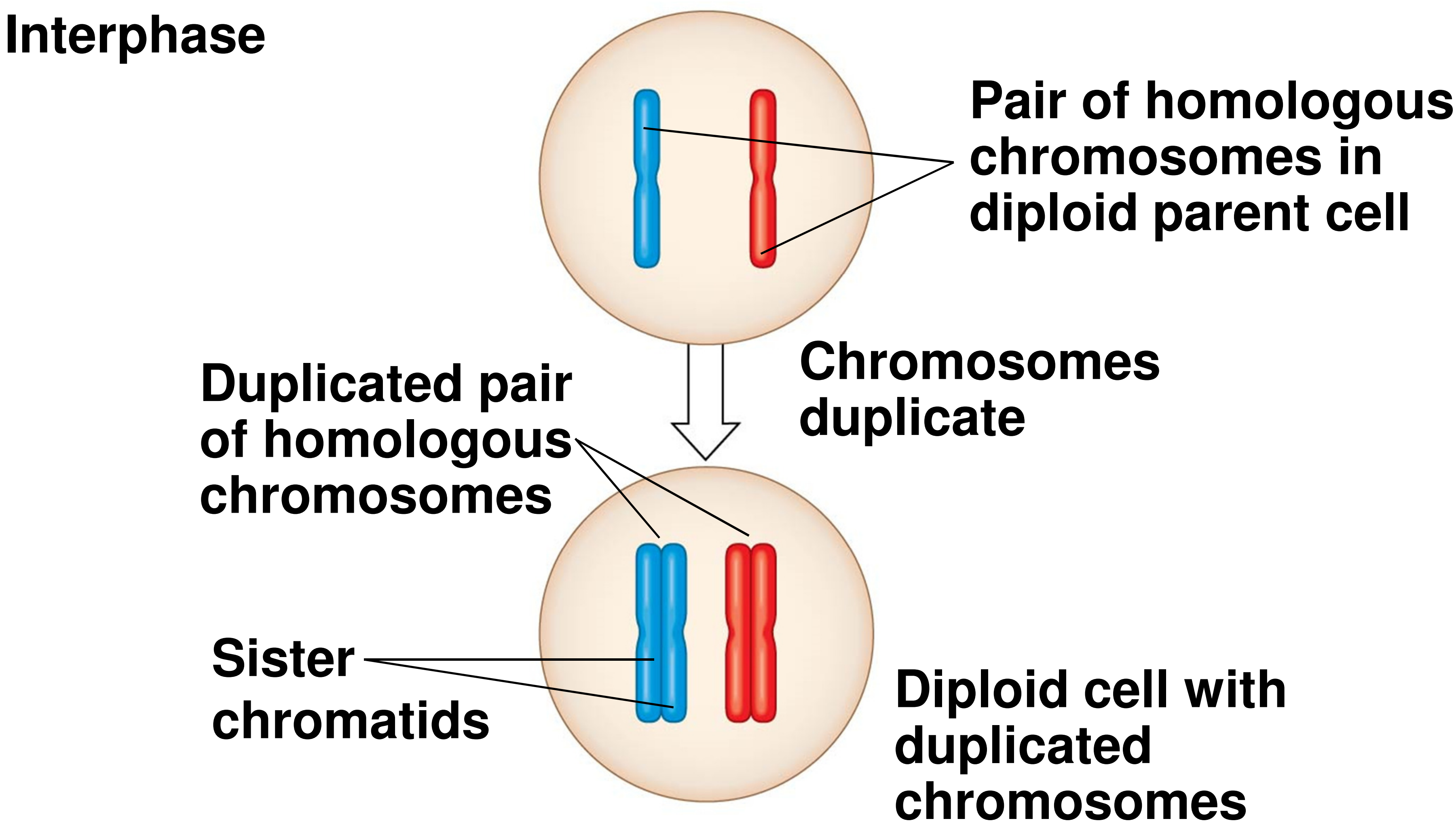
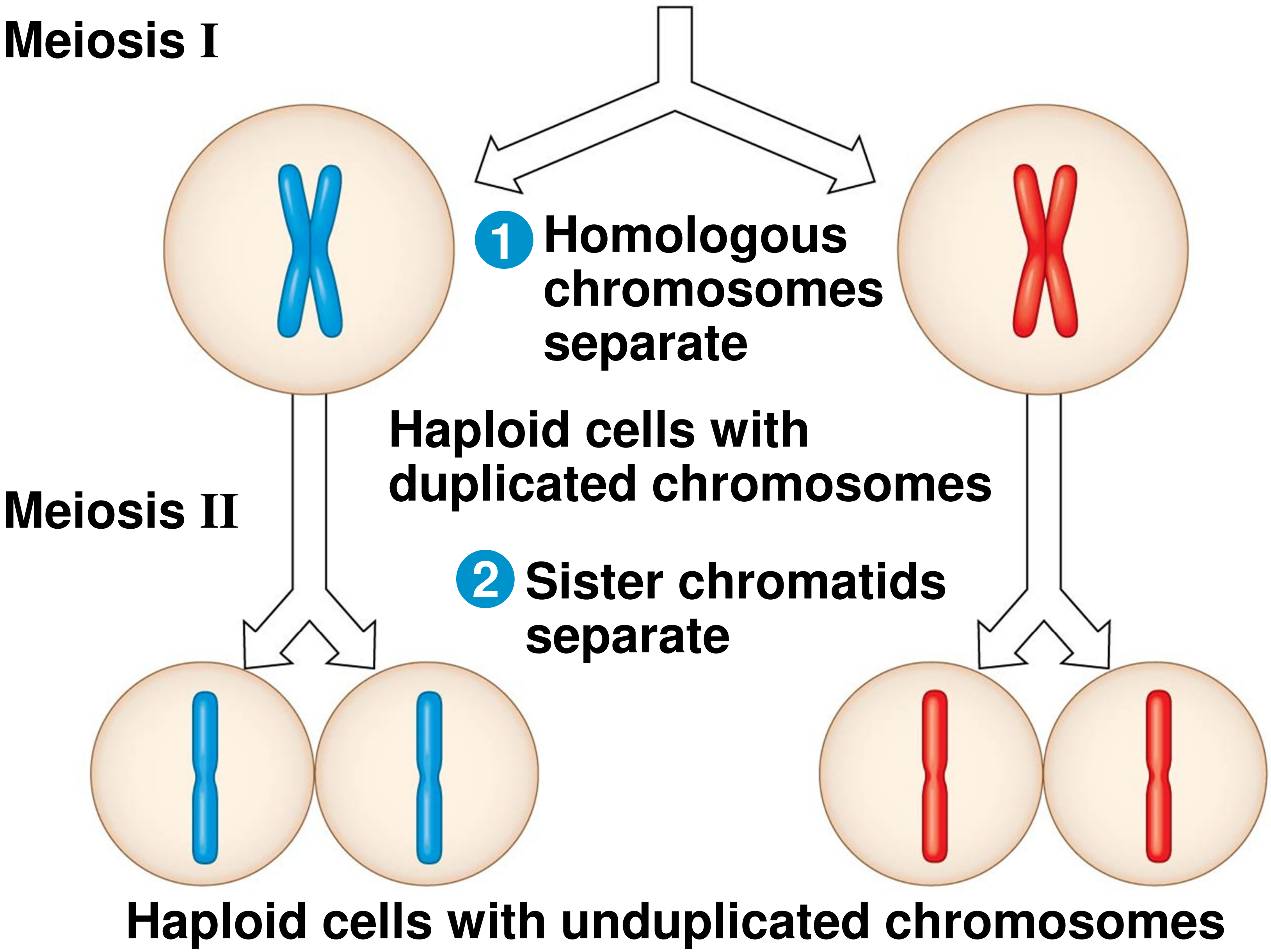

Interphase
Pair of homologous chromosomes in diploid parent cell
Chromosomes duplicate
Duplicated pair of homologous chromosomes
Sister chromatids
Diploid cell with duplicated chromosomes

Figure 10.7b



Meiosis I
1 Homologous chromosomes separate
Haploid cells with duplicated chromosomes
Meiosis II
2 Sister chromatids separate
Haploid cells with unduplicated chromosomes

Prophase I

- Chromosomes begin to condense
- In **synapsis**, homologous chromosomes loosely pair up, aligned gene by gene
- In **crossing over**, nonsister chromatids exchange DNA segments

Metaphase I

- Tetrads line up at the metaphase plate, with one chromosome facing each pole

Anaphase I

- Pairs of homologous chromosomes separate
- One chromosome moves toward each pole
  - Sister chromatids remain attached at the centromere and move as one unit toward the pole

Telophase I

- 2 nuclear envelopes reform
  - Each half of the cell has a haploid set of chromosomes
  - Each chromosome still consists of two sister chromatids

Cytokinesis

- Division of cytoplasm usually occurs simultaneously to telophase I, forming two haploid daughter cells
- In animal cells, a cleavage furrow forms
- In plant cells, a cell plate forms
- No chromosome replication occurs between the end of meiosis I and the beginning of meiosis II
  - Because the chromosomes are already replicated!
- 2 cells enter Meiosis II
  - Meiosis II is very similar to mitosis!
  - But because of crossing over in meiosis I, the two sister chromatids of each chromosome are no longer genetically identical

Prophase II

- In prophase II, a spindle apparatus forms
- No crossing over!

Metaphase II

- Sister chromatids line up at the metaphase plate

Anaphase II

- Sister chromatids separate
  - The sister chromatids of each chromosome now move as two newly individual chromosomes toward opposite poles

Telophase II and Cytokinesis

- Chromosomes arrive at opposite poles, nuclei form, and the chromosomes begin decondensing

- At the end of meiosis, there are
  - Four daughter cells
  - Each with a haploid set of unduplicated chromosomes
  - Each daughter cell is genetically distinct from the others and from the parent cell

Figure 10.8a

MEIOSIS I: Separates homologous chromosomes

Prophase I	Metaphase I	Anaphase I	Telophase I and Cytokinesis

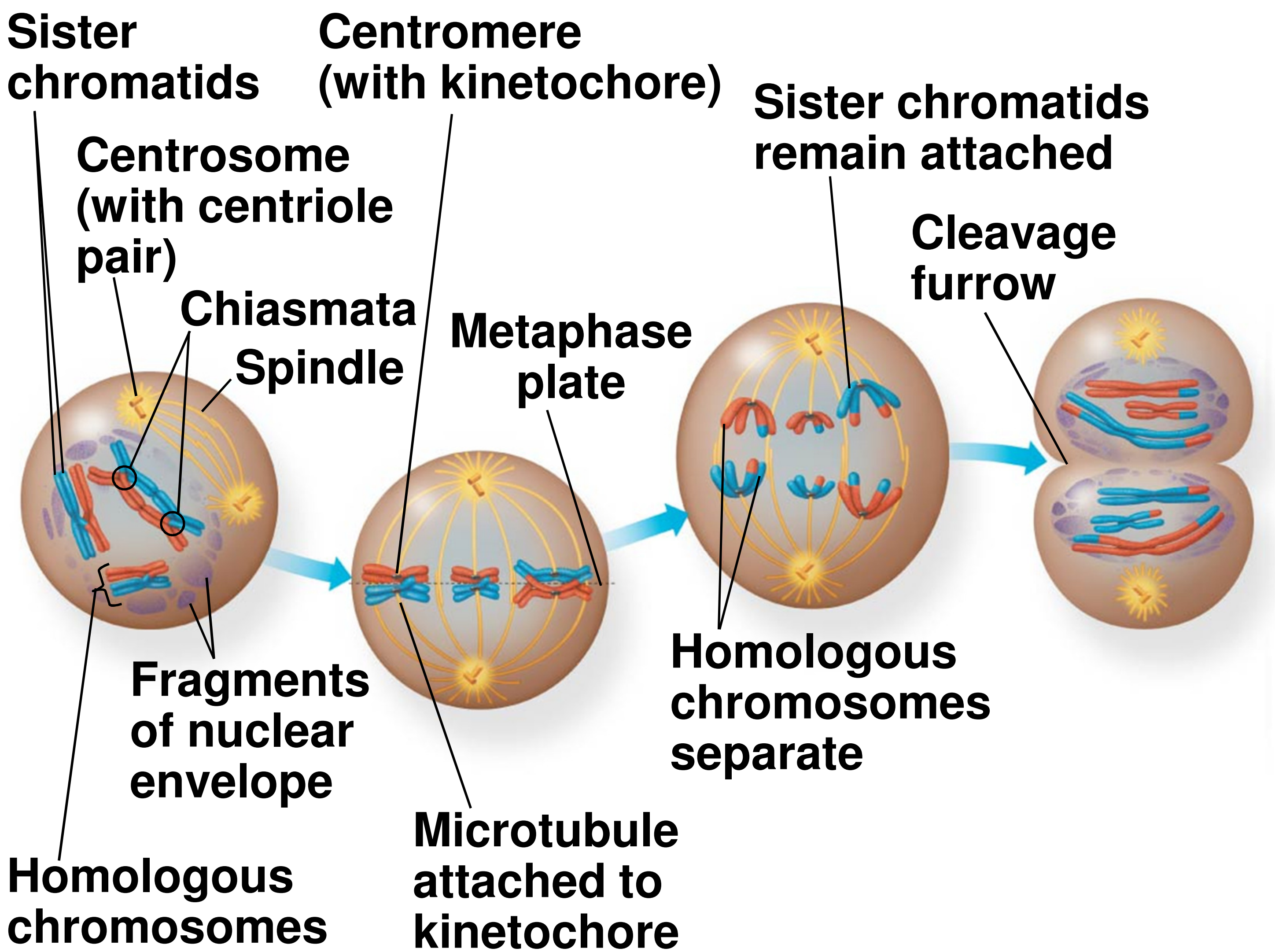
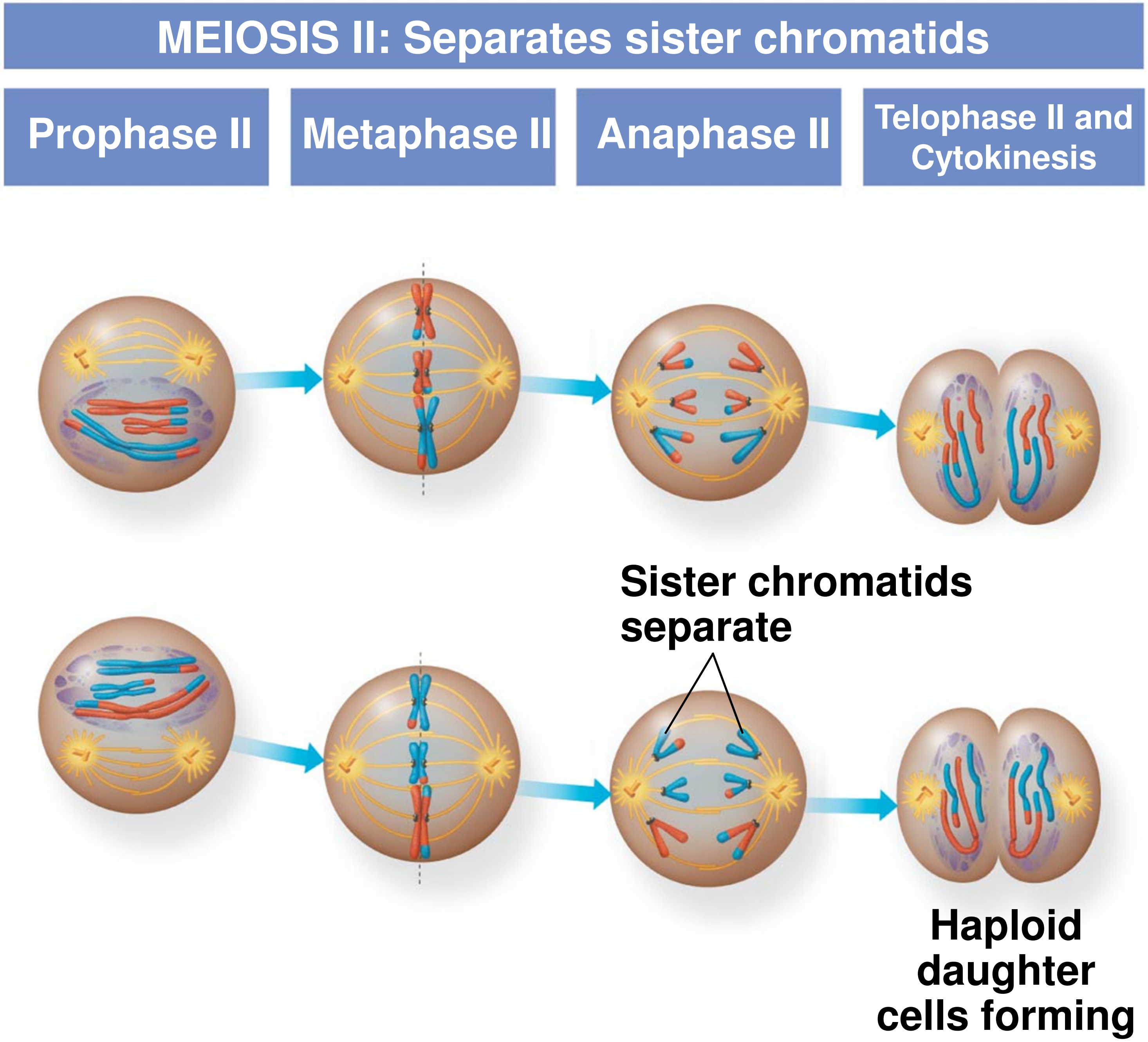


Figure 10.8b


MEIOSIS II: Separates sister chromatids
Prophase II
Metaphase II
Anaphase II
Telophase II and Cytokinesis
Sister chromatids separate
Haploid daughter cells forming

Comparison of Mitosis and Meiosis

Mitosis	Meiosis
• One division	• Two divisions
• 2 daughter cells	• 4 daughter cells
• Daughter cells genetically identical	• Daughter cells genetically different
• Chromosome # of daughter cells same as that of parent cell (diploid)	• Chromosome # of daughter cells half that of parent cell (haploid)
• Occurs in body cells	• Occurs in reproductive cells
• Used for growth, repair, and asexual reproduction	• Used for sexual reproduction, producing new gene combinations

- Three events are unique to meiosis, and all three occur in meiosis I
  - **Synapsis and crossing over** in prophase I: Homologous chromosomes physically connect and exchange genetic information
  - **Homologous pairs at the metaphase plate**: Homologous pairs of chromosomes are positioned there in metaphase I
    - **Independent assortment**
  - **Separation of homologs** during anaphase I

Genetic Variation

- Mutations (changes in an organism's DNA) are the original source of genetic diversity
- Mutations create different versions of genes called alleles
- Reshuffling of alleles during sexual reproduction produces genetic variation by the following mechanisms
  1. Independent assortment of chromosomes
  2. Crossing over
  3. Random fertilization

- Natural selection results in the accumulation of genetic variations favored by the environment
  - Individuals best suited to the environment leave the most offspring, thereby transmitting their genes
- Sexual reproduction contributes to the genetic variation in a population, which originates from mutations
  - Genetic variation is evolutionarily advantageous
- Asexual reproduction is less expensive than sexual reproduction

Unit 4
Cell Division

Chapter 16: Development

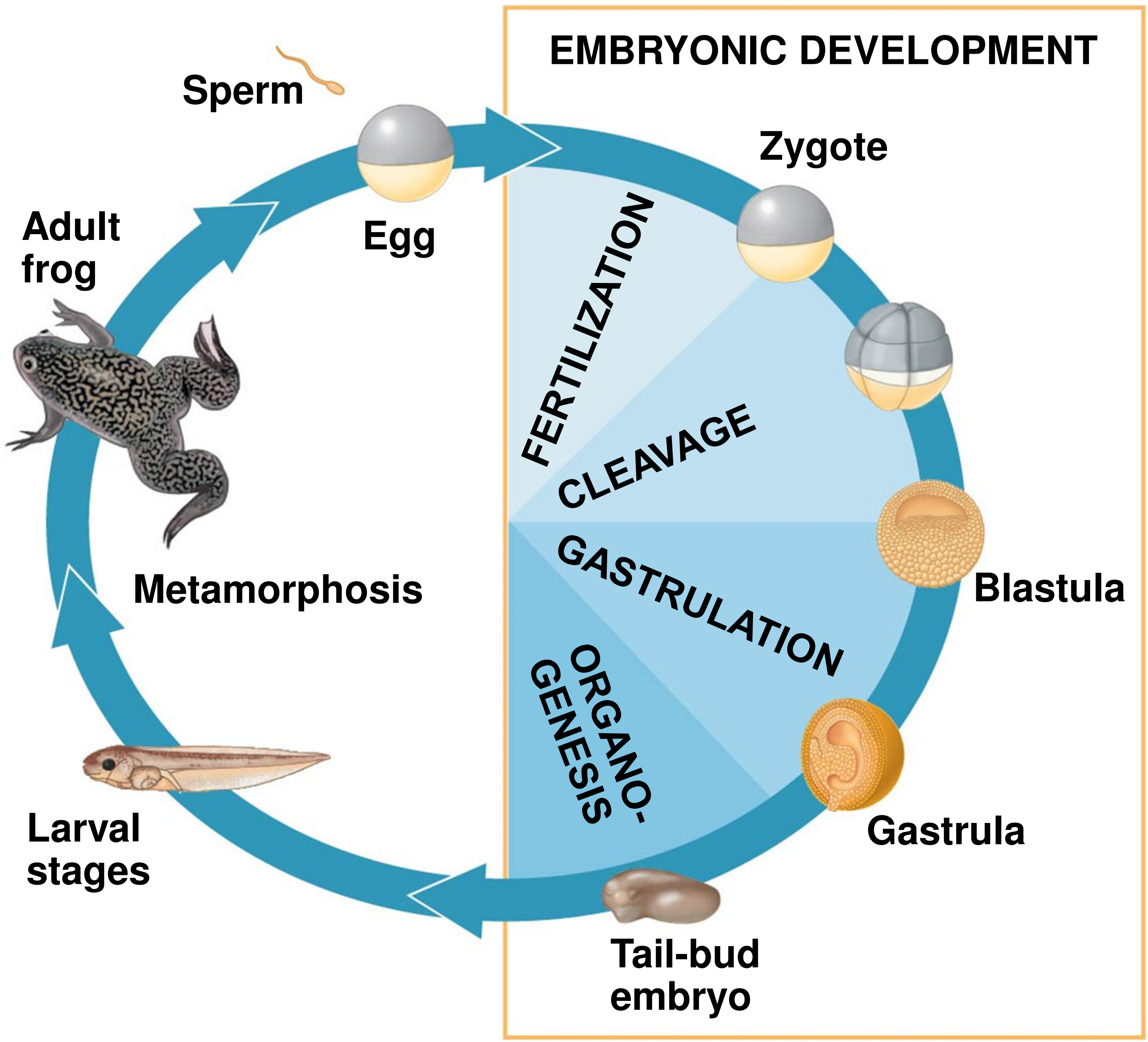
Differential Gene Expression

- A fertilized egg gives rise to many different cell types
- Cell types are organized successively into tissues, organs, organ systems, and the whole organism
- Gene expression orchestrates the developmental programs of animals
- The transformation from zygote to adult results from
  - Cleavage (cell division)
  - Cell differentiation
  - Pattern formation
  - Morphogenesis
  - Cell growth
  - Cell death (apoptosis)

Embryonic Development

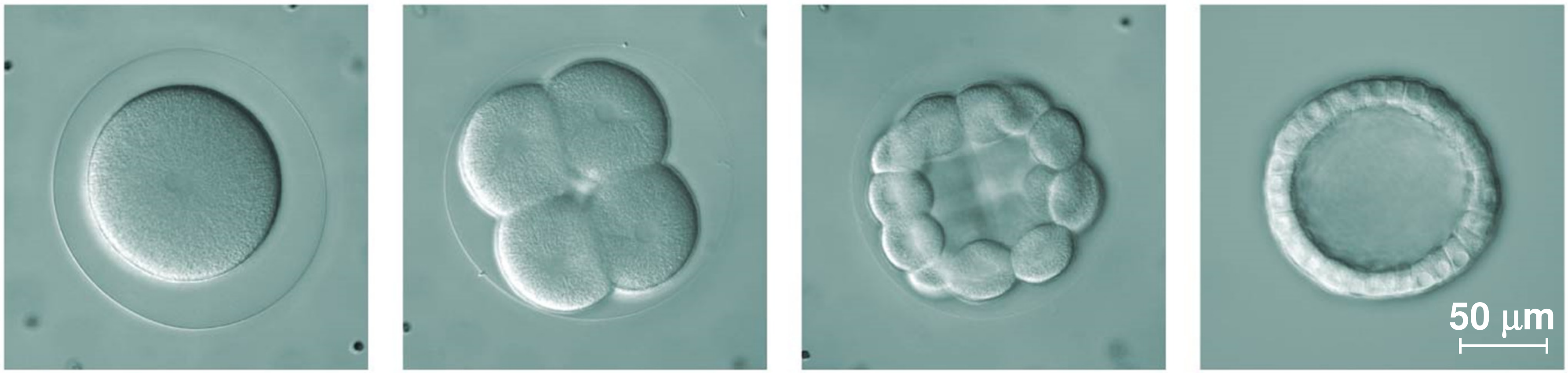
- Across animal species, embryonic development involves common stages occurring in a set order
  1. Fertilization, which forms a zygote
  2. Cleavage
     - A period of rapid cell division without growth
     - Followed by **morphogenesis**
       – SHAPE!
  3. Blastula
     - Ball of cells with a fluid-filled cavity called a **blastocoel**
  4. Gastrula
     - 3-layered embryo

Figure 36.14



EMBRYONIC DEVELOPMENT
Sperm
Egg
Zygote
FERTILIZATION
CLEAVAGE
GASTRULATION
ORGANO-
GENESIS
Blastula
Gastrula
Tail-bud
embryo
Larval
stages
Metamorphosis
Adult
frog

Figure 36.17



(a) Fertilized egg **(b) Four-cell stage** **(c) Early blastula** **(d) Later blastula**

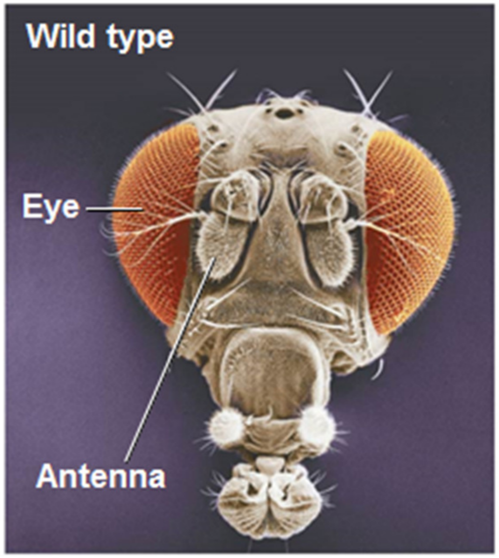
- During **gastrulation**, cell layers are established
  - The hollow blastula is reorganized into a two- or three-layered embryo called a **gastrula**
- The cell layers produced by gastrulation are called germ layers
  - The **ectoderm** forms the outer layer
    - Gives rise to outer covering and nervous system
  - The **endoderm** forms the inner layer
    - Gives rise to lining of digestive tract, liver, lungs
  - In vertebrates and other animals with bilateral symmetry, a third germ layer, the **mesoderm**, forms between the two
    - Gives rise to muscles and most other organs between digestive tract and outside
    - Note: Mesoderm is absent in cnidarians

- Cell **differentiation** is the process by which cells become specialized in structure and function
- The physical processes that give an organism its <u>shape</u> constitute **morphogenesis**
- Activities of a cell depend on the genes it expresses and the proteins it produces
  - Cells in an organism have the same genome
  - So differential gene expression results from genes being regulated differently in each cell type
- Transcription remains the principal regulatory point for maintaining appropriate gene expression
- Some "master regulatory genes" have been identified

- While most cells are differentiating in a developing organism, some are genetically programmed to die
- **Apoptosis** is “programmed cell death”
- Apoptosis also occurs in the mature organism in cells that are infected, damaged, or at the end of their functional lives
- Apoptosis is essential to development and maintenance in all animals
- In vertebrates, apoptosis is essential for normal nervous system development and morphogenesis of hands and feet (or paws)

- **Pattern formation** is the development of a spatial organization of tissues and organs
  - In animals, pattern formation begins with the establishment of the major axes
- **Positional information** are the collective molecular cues that control pattern formation
  - Tells a cell its location relative to the body axes and to neighboring cells

- **Homeotic genes** =
  - Regulatory genes that control pattern formation in late embryo, larva, and adult stages
  - **Homeobox** =
    - 180-nucleotide sequence within homeotic and other developmental genes
- Homeotic genes in animals are named *Hox genes*
- Different combinations of homeobox genes are active in different parts of an embryo
  - This selective expression of regulatory genes is central to pattern formation



- Hox genes regulate all of the transcription factors to turn on all of the genes required for a specific part of development
  - Hox genes are master regulatory genes
  - They control the transcription of transcription factors
    - Can turn genes on or off
  - Hox genes are highly conserved in all animals

Axis Establishment

- <u>Gradients</u> of substances called **morphogens** establish an embryo’s axes and other features
- For example, the ***bicoid*** gene, affects the <u>anterior</u> (front) end of the body
- An embryo whose mother has no functional *bicoid* gene lacks the front half of its body and has duplicate posterior structures at both ends
- If bicoid mRNA is injected into various regions of an embryo, the result is formation of <u>anterior</u> structures at site of injection